Single top or bottom production associated with a scalar in γp collision as a probe of topcolor-assisted technicolor

Guo-Li Liu[*]

Department of Physics, Zhengzhou University, Zhengzhou, China

Abstract

In the framework of the topcolor-assisted technicolor (TC2) models, we study the productions of a single top or bottom quark associated with a scalar in γ-p collision, which proceed via the subprocesses $c\gamma \to t\pi_t^0$, $c\gamma \to th_t^0$ and $c\gamma \to b\pi_t^+$ mediated by the anomalous top or bottom coupling $tc\pi_t^0$, tch_t^0 and $bc\pi_t^+$. These productions, while extremely suppressed in the Standard Model, are found to be significantly enhanced in the large part of the TC2 parameter space, especially the production via $c\gamma \to b\pi^+$ can have a cross section of 100 fb, which may be accessible and allow for a test of the TC2 models.

---

[*]Email:guoliliu@zzu.edu.cn

I. INTRODUCTION

The physics of the top quark [1] will be intensively studied in the coming years. The CERN Large Hadron Collider (LHC) will copiously produce top quarks and allow to scrutinize top quark properties. Any new physics related to the top quark will be uncovered or stringently constrained [2]. One striking property of top quark in the Standard Model (SM) is its extremely weak flavor-changing neutral-current (FCNC) interactions due to the GIM mechanism: they are absent at tree-level and highly suppressed at loop-level [3]. Therefore, the study of top quark FCNC processes will serve as a sensitive test of the SM and a powerful probe of new physics.

In the extensions of the SM, the top quark FCNC interactions may be enhanced through two ways. One is that at loop-level the GIM machanism does not work so well since the loops may contain new particles, such as the superparticles predicted in supersymmetric models [4] and the mirror particles in little Higgs models [5]. The other is that some models like the TC2 models [6] may predict tree-level top quark FCNC Yukawa couplings with scalar fields, which is in contrast with the SM where the generation of fermion masses is realized by simply introducing Yukawa couplings with only one Higgs doublet and, as a result, the Yukawa couplings can be diagonalized simultaneously with the fermion mass matrices. For the top quark FCNC interaction tch, although it can be greatly enhanced in new physics models, the extent of enhancement is different for different models. At the same time, in TC2 models a large flavor mixing between the right-handed top and charm quarks can also induce a large Yukawa coupling $bc\pi_t^+$ (this is in contrast to the usual Cabibbo-Kobayashi-Maskawa (CKM) mixing which involves only left-handed fermions in the charged weak current). So both the FCNC top couplings tch ($h = \pi_t^0, h_t^0$) and the flavor-changing bottom coupling $bc\pi_t^+$ are quite special in TC2 models, which may serve as a sensitive probe of TC2 models.

Since the exotic top or bottom processes induced by the anomalous couplings in TC2 models have been studied for hadron or linear colliders [7], we in this work focus on the relevant processes in the lepton-hadron collisions. As we know, the linac-ring type colliders [8] were proposed more than thirty years ago. Starting from the 1980's, this idea has been revisited with the purposes of achieving high luminosities and high energies. Generally speaking, the most popular ep colliders are based on the following suggestions. Firstly, THERA [9] with $\sqrt{s} = 1 - 1.6$ TeV and $L = 10^{31} cm^{-2} s^{-1}$ was included in the TESLA

TDR [10]; Secondly, the possibility to intersect CLIC (70 GeV) with LHC [11] was discussed as a QCD explorer; Finally, a comparison of e-linac and e-ring versions of the LHC and VLHC based ep colliders is performed in Ref. [12] and the linac options are shown to be preferable. Correspondingly, γp colliders [13] with the same order of luminosity and energy can be realized on the base of the linac-ring ep colliders using the Compton backscattering of laser beam off the high energy electron beam.

It is known that the linac-ring type colliders have been playing a crucial role in particle experiments [8, 13]. For example, the HERA with $\sqrt{s} = 0.3$ TeV extended the kinematical region by two orders both in high Q^2 and small x with respect to the fixed target experiments. However, the region of sufficiently small x ($\leq 10^{-5}$) and simultaneously high Q^2 (≥ 10 GeV^2), where saturation of parton densities should manifest itself, is not currently achievable. The investigation of physics phenomena at extreme small x but sufficiently high Q^2 is very important for understanding the nature of strong interactions at all levels from nucleus to partons. At the same time, the results from the linac-ring type colliders are necessary for adequate interpretation of physics at future hadron colliders. Concerning the on-going LHC, an ep or γp collider with $\sqrt{s} \simeq 1$ TeV will be very useful for the precision era of the LHC. Such a linac-ring collider is competitive to future hadron or linear colliders in search for the new physics.

In this work we focus on the high energy ep collider [8, 13] and assume the center-of-mass energy $\sqrt{s} = 1$ TeV for an illustration. We will study the productions of a single top or bottom quark associated with a scalar in the γ-p collision option of such an ep collider, which proceed via the subprocesses $c\gamma \to t\pi_t^0$, $c\gamma \to th_t^0$ and $c\gamma \to b\pi_t^+$ mediated by the anomalous top coupling $tc\pi_t^0$, tch_t^0 and $bc\pi_t^+$. These processes may also serve as one of the materials to demonstrate the necessity of constructing the ep and γp collider. This work is organized as follows. In sec. II we take a look at the TC2 models, and give the Feynamn rules needed in the calculation. In Sec. III we present the calculations for the processes at the γp colliders. Discussions and the conclusion are given in Sec. IV.

II.   TC2 MODEL AND THE RELEVANT COUPLINGS

To solve the phenomenological difficulties of traditional TC theory, TC2 theory[6] was proposed by combing TC interactions with the topcolor interactions for the third generation

3

at the scale of about 1 TeV. In TC2 theory, the TC interactions play a main role in breaking the electroweak symmetry. The Extended TC(ETC) interactions give rise to the masses of the ordinary fermions including a very small portion of the top quark mass, namely ϵm_t with a model dependent parameter $\epsilon \ll 1$. The topcolor interactions also make small contributions to the EWSB, and give rise to the main part of the top quark mass, $(1-\epsilon)m_t$.

After all of the dynamical symmetry breaking there are three Nambu-Goldstone bosons (NGB) from the TC sector, and three NGBs from top condensation sector. One linear combination of these, mostly favoring the TC NGBs, will become the longitudinal $W_L^\pm$ and Z_L. The orthogonal linear combination will appear in the spectrum as an isovector multiplet of pseudo-NGB(PNGB)s, $\tilde{\pi}^a$. These objects acquire mass as a consequence of the interference between the dynamical and ETC masses of the top quark, i.e., the masses of the $\tilde{\pi}^a$ will be proportional to ϵ. We refer to the $\tilde{\pi}^a$ as *top-pions* $(\pi_t^\pm, \pi_t^0)$. For $\epsilon \lesssim 0.05 - 0.10$, we will find that the top-pions have masses of order ~ 200 GeV. They are phenomenologically forbidden from occurring much below ~ 165 GeV [14] due to the absence of the decay mode $t \to \pi_t^+ + b$.

On the other hand, the generation of a large fermion mass such as m_t is a difficult problem in theories of dynamical EWSB. The idea of the top quark mass as a "constituent", dynamical mass generated by the presence of a condensate $\langle \bar{t}t \rangle$ addresses this problem, providing at the same time a source of dynamical EWSB not requiring large amounts of new matter. In the original top-condensation standard model [15], the formation of the $\langle \bar{t}t \rangle$ condensate is fully responsible for the masses of the SM gauge bosons as well as for the dynamical generation of m_t. If the scale of the interaction driving the condensation is Λ, then at lower energies there is a scalar doublet, the top-Higgs, which acquires a vacuum expectation value (VEV). Just as in the SM, the NGB are eaten by the W and Z, leaving a neutral, CP-even scalar particle in the spectrum.

In the TC2 scenario the top-pions acquire masses in the range $m_{\pi_t} \simeq (100 - 300)$ GeV. The neutral CP-even state analogous to the σ particle in low energy QCD, the top-Higgs, is a $t\bar{t}$ bound state and its mass can be estimated in the Nambu–Jona-Lasinio (NJL) model in the large N_c approximation, to be

$$m_h \simeq 2m_t. \tag{1}$$

This estimate is rather crude and it should be taken as a rough indication of where the

top-Higgs mass could be. Masses well below the $t\bar{t}$ threshold are quite possible and occur in a variety of cases [16].

For TC2 models, the underlying interactions, i.e. topcolor interactions, are non-universal and therefore do not possess a GIM mechanism. When the non-universal interactions are written in the mass eigenstates, it may lead to the flavor changing coupling vertices of the new particles. Such as, the neutral scalars predicted by this kind of models have the flavor changing scalar coupling vertices. The coupling forms of the scalars $\pi_t^{\pm}$, π_t^0 and h_t^0 to the ordinary fermions can be written as[6, 7]:

$$\frac{m_t}{\sqrt{2}F_t}\frac{\sqrt{v_w^2-F_t^2}}{v_w} \quad [\quad K_{UR}^{tc}K_{UL}^{tt*}\bar{t}_Lc_Rh_t^0 + \sqrt{2}K_{UR}^{tt*}K_{DL}^{bb}\bar{t}_Rb_L\pi_t^+$$
$$+ iK_{UR}^{tc}K_{UL}^{tt*}\bar{t}_Lc_R\pi_t^0 + \sqrt{2}K_{UR}^{tc*}K_{DL}^{bb}\bar{c}_Rb_L\pi_t^+ + h.c.], \qquad (2)$$

here the factor $\sqrt{v_w^2-F_t^2}/v_w$ ($F_t = 50$ GeV, $v_w \simeq 174$ GeV) reflects the effect of the mixing between the top-pions and the would-be Goldstone bosons [17]. K_{UL}, K_{DL} and K_{UR} are the rotation matrices that transform respectively the weak eigenstates of left-handed and right-handed up-type quarks to their mass eigenstates, which can be parametrized as [7]

$$K_{UL}^{tt} \simeq K_{DL}^{bb} \simeq 1, \quad K_{UR}^{tt} \simeq \frac{m_t'}{m_t} = 1-\epsilon, \quad K_{UR}^{tc} \leq \sqrt{1-(K_{UR}^{tt})^2} = \sqrt{2\epsilon - \epsilon^2}, \qquad (3)$$

with m_t' denoting the topcolor contribution to the top quark mass. In Eqn.(2) we neglected the mixing between up quark and top quark.

We can see from Eqn.(2) that only a factor i, the imaginary unit, is different between the $tc\pi_t^0$ and the tch_t^0 couplings, so the squares of the total amplitude of the two processes $c\gamma \to t\pi_t^0$ and $c\gamma \to th_t^0$ are the same with the same scalar masses. We in following discussion, take the neutral top-pion π_t^0 as an example unless stated otherwise.

Note that the $tc\pi_t^0$ and $bc\pi_t^+$ couplings are quite large in the TC2 prediction, the $bc\pi_t^+$ coupling strength, $Y \sim \frac{m_t}{F_t}\frac{\sqrt{v_w^2-F_t^2}}{v_w}K_{UR}^{tc} \sim 3K_{UR}^{tc}$ with $0.1 \leq K_{UR}^{tc} \leq 0.43$, so there is no wonder that one expects they may induce larger contributions to the relevant processes. At the same time, the coupling strength yields $Y^2/4\pi \simeq 0.11$ for $K_{UR}^{tc} = 0.4$, so we can safely conclude that the TC2 coupling as Eqn. 2 still makes the perturbative expansion valid in spite of its large value.
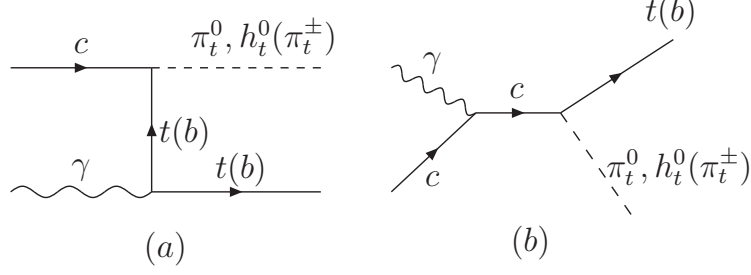
Figure 1: Feynman diagrams for the tS productions $\gamma c \to qS$ ($S = \pi_t^0$, h_t^0, $\pi_t^\pm$ and $q = t$ or b) mediated by the anomalous couplings $tc\pi_t^0$, tch_t^0 and $bc\pi_t^\pm$.

III. CALCULATION

A. Analytical discussion

The productions of the neutral and charged top-pions at the γp collision is mediated by the flavor changing $t - c - \pi_t^0$ and $b - c - \pi_t^+$ via the subprocess $\gamma c \to t\pi_t^0$ and $\gamma c \to b\pi_t^\pm$ with the relevant Feynman diagrams shown in Figure 1. Using the couplings given in Eqn.2, we can write the amplitude M_1 and M_2 of the subprocesses $\gamma c \to t\pi_t^0$ and $\gamma c \to b\pi_t^+$, respectively:

$$M_1 = eQ_c \frac{m_t}{\sqrt{2}F_t} \frac{\sqrt{v_w^2 - F_t^2}}{v_w} K_{UR}^{tc} K_{UL}^{tt*} \epsilon^\mu \bar{u}_t (P_R \frac{\not{p}_c + \not{p}_\gamma}{(p_c + p_\gamma)^2} \gamma^\mu + \gamma^\mu \frac{\not{p}_t - \not{p}_\gamma + m_t}{(p_t - p_\gamma)^2 - m_t^2} P_R) u_c,$$

$$M_2 = e \frac{m_t}{\sqrt{2}F_t} \frac{\sqrt{v_w^2 - F_t^2}}{v_w} K_{UR}^{tc} K_{DL}^{bb} \epsilon^\mu \bar{u}_b (Q_c P_R \frac{\not{p}_c + \not{p}_\gamma}{(p_c + p_\gamma)^2} \gamma^\mu + Q_b \gamma^\mu \frac{\not{p}_t - \not{p}_\gamma + m_b}{(p_t - p_\gamma)^2 - m_b^2} P_R) u_c,$$

Where $P_R = (1 + \gamma_5)/2$, $Q_c = 2/3$, $Q_b = -1/3$, the charge of charm quark(bottom quark) and $p_{t,c,\gamma}$ are the momentum of top quark, charm quark and photon, respectively.

The cross sections for the subprocess $c\gamma \to t\pi_t^0$ and $c\gamma \to t\pi^+$ are

$$\hat{\sigma}(\hat{s}) = \int_{\hat{t}_{min}}^{\hat{t}_{max}} \frac{1}{16\pi\hat{s}^2} \overline{M}^2 d\hat{t}, \tag{4}$$

with

$$\hat{t}_{max,min} = \frac{1}{2} \left\{ m_t^2 + m_\pi^2 - \hat{s} \pm \sqrt{[\hat{s} - (m_t + m_\pi)^2][\hat{s} - (m_t - m_\pi)^2]} \right\}. \tag{5}$$

Where $\sqrt{\hat{s}}$ is the center-of-mass energy of the subprocesses in $c\gamma$ collision.

6

The total cross-section for the main process $\gamma q \to q \pi_t$ is obtained after the integration of $\hat{\sigma}$ over the quark and photon distributions. For this purpose we make the following change of variables: first expressing $\hat{s}$ as $\hat{s} = x_1 x_2 s$ where $\hat{s} = s_{\gamma q}$, $s = s_{ep}$, $x_1 = E_\gamma / E_e$, $x_2 = E_q / E_p$ and furthermore calling $\tau = x_1 x_2$, $x_2 = x$ then one obtains $dx_1 dx_2 = dx d\tau / x$. The limiting values are $x_{1,max} = 0.83$ in order to get rid of the background effects in the Compton backscattering, particularly $e^+ e^-$ pair production in the collision of the laser with the high energy photon in the conversion region, $x_{1,min} = 0$, $x_{2,max} = 1$, $x_{2,min} = \frac{\tau}{0.83}$, $\hat{s}_{min} = (m_q + M_\pi)^2 / s$. Then we can write the total cross-section as[18, 19] :

$$\sigma(s) = \int_{\hat{s}_{min}}^{0.83} d\tau \int_{\tau/0.83}^{1} dx \frac{1}{x} f_\gamma(\frac{\tau}{x}) f_c(x) \hat{\sigma}(\hat{s}) \tag{6}$$

where $F_{\gamma/e}$ denotes the energy spectrum of the back-scattered photon for unpolarized initial electron and laser photon beams given by[20]

$$F_{\gamma/e}(x) = \frac{1}{D(\xi)} \left(1 - x + \frac{1}{1-x} - \frac{4x}{\xi(1-x)} + \frac{4x^2}{\xi^2(1-x)^2} \right). \tag{7}$$

The definitions of parameters ξ, $D(\xi)$ and x_{max} can be found in [20]. In our numerical calculation, we choose $\xi = 4.8$, $D(\xi) = 1.83$ and $x_{max} = 0.83$. $f_c(x)$ is the distribution of charm-quarks inside the proton.

In our numerical calculation, we use the CTEQ6L [21] parton distribution functions and take factorization scale Q and the renormalization scale μ_F as $Q = \mu_F = m_t(m_b) + M_\pi$. To make our predictions more realistic, we applied some kinematic cuts. We require that the energy of γ and the initial charm quark be larger than 15 GeV and the separation of two particles states be more than 15° in the center-of-mass frame. Moreover, For the final particles, we require that the transverse momentum of each produced particle be larger than 15 GeV.

B. Numerical results

For the SM parameters, we take $m_t = 172.7$ GeV, $m_c = 1$ GeV, $m_b = 5$ GeV, $\alpha_e = 1/128.8$ [22] and use the one-loop running coupling constant $\alpha_s(Q)$.

As for the TC2 parameters, we will consider the masses of the scalars equal to each other, i.e, top-pions, neutral and charged, denoted as M_π when not considering the difference between them. Considering the discussion in the previous section, we assume M_π are in the range $200 - 400$ GeV, $\epsilon \sim 0.01 - 0.08$.
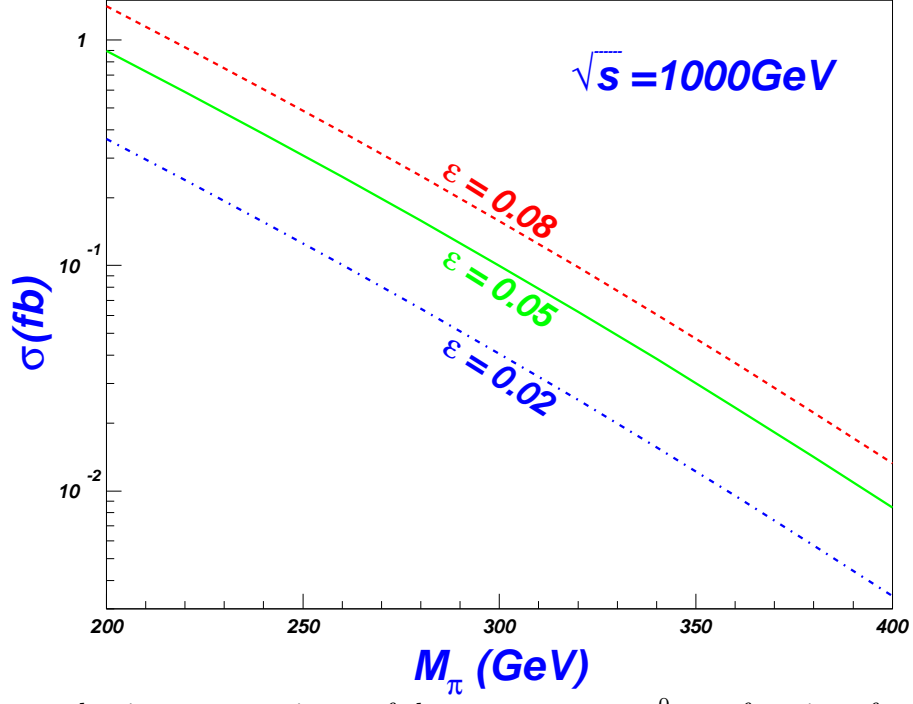
Figure 2: The production cross section σ of the process $c\gamma \to t\pi_t^0$ as a function of $m_{\pi_t^0}$ for $\sqrt{s} = 1$ TeV and three values of the parameter ϵ.

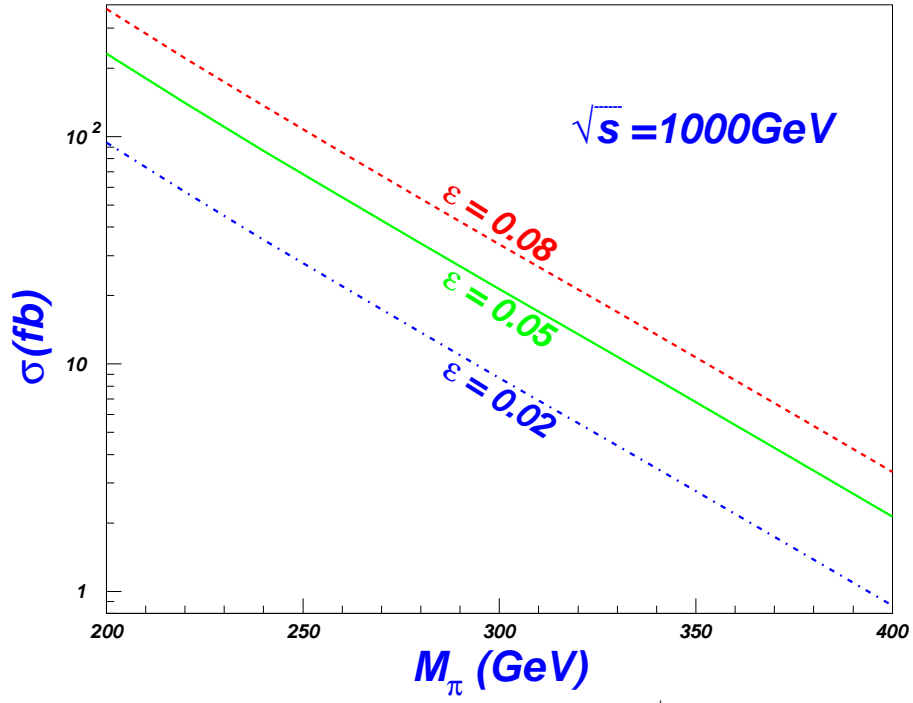Figure 3: The production cross section σ of the process $c\gamma \to t\pi_t^{\pm}$ as a function of $m_{\pi_t^{\pm}}$ for $\sqrt{s} = 1$ TeV and three values of the parameter ϵ.
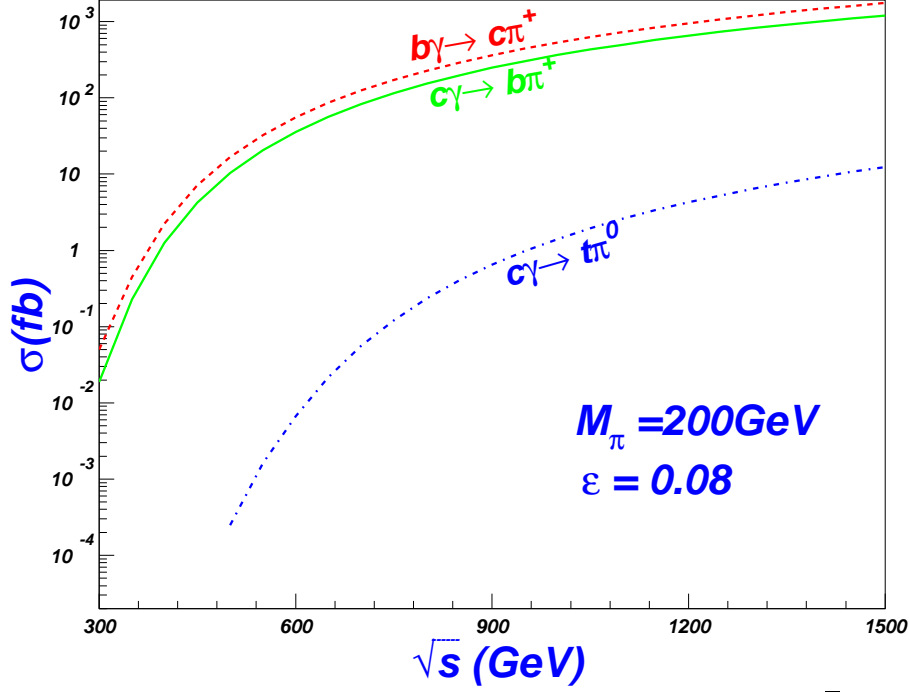
Figure 4: The production cross section σ of the processes as a function of $\sqrt{s}$ for $M_\pi = 200 GeV$ and $\epsilon = 0.08$.

The production cross sections of the top-pion π_t^0 and $\pi_t^\pm$ at the γp collider are plotted in Figure 2 and Figure 3, respectively, as functions of the top-pion mass M_π and three values of the parameter ϵ: $\epsilon = 0.02, 0.05, 0.08$ for $\sqrt{s} = 1000 GeV$. We can see that the production cross sections decrease rapidly with increasing M_π since the final phase space are depressed by the increasing masses of the final scalars. We can also see from the two figures that the π_t^+ production cross section is far much larger than that of the neutral top-pion in all of the parameter space. The reason is that, firstly, the final phase space of the $t\pi_t^0$ is depressed by the top mass comparing to the $b\pi_t^+$ production, and secondly, the neutral top-pion has a large top mass propagator which could also depress the result. For $200 GeV \leq M_\pi \leq 400 GeV$ and $0.02 \leq \epsilon \leq 0.08$, the production cross sections of the neutral and the charged top-pion at the γp collider are about 1 fb and 100 fb, respectively. Therefore there may be hundreds of thousand $b\pi_t^+$ events to be generated per year in most of the parameter space of the TC2 models. Thus, it is quite easy to detect the productions of the charged scalars via the processes $c\gamma \to b\pi_t^+$ at the γp collisions.

Note that the subprocess $b\gamma \to c\pi_t^+$ can also be realized, but it is almost the same as the process $c\gamma \to b\pi_t^+$ with the opposite fermion current. What makes the difference between the cross section of the two processes is the parton distribution function since one has the quark

c in the initial states, while the other is the b quark. We believe, however, the difference are small, so we can safely assume the two processes have the same cross section, which has been verified by our calculation. To feel it, we show the dependence of the cross section on the $\sqrt{s}$ in Fig.4, the same figure as the other processes for comparing with each other.

We should also note that in Ref.[23] the top-pion production is also discussed, however, it is based on the effective coupling $t - c - \gamma$ at the one-loop level, while in our discussion, the processes are induced by the flavor changing coupling of the scalars directly $t - c - \pi_t^0$ or $b - c - \pi_t^\pm$ at the tree level.

Despite the small probability, however, we believe that the top-pion γp productions are almost free of SM backgrounds since the $\pi_t^0 t\bar{c}$ and $\pi_t^+ b\bar{c}$ couplings in SM are extremely small due to the GIM mechanism and the small V_{bc} (~ 0.04) value in the CKM matrix.

Figure 4 displays the dependence of the cross section on the center-of-mass (CM) energy $\sqrt{s}$ (For an simplicity of the statement, we here assume the region of the $\sqrt{s}$ describes the CM energy varying from HERA to THERA in the following discussion.), taking $M_\pi = 200$ GeV, and $\epsilon = 0.08$, from which we can see the cross section of charged top-pion production has to go down as we get closer to the $m_j + M_\pi$ $(j = b, c)$ threshold region and that all the cross sections increase with the increasing $\sqrt{s}$, which is one of the main goal for us to raise the collider energy, i. e, to upgrade the HERA to THERA collider since the latter can provide much larger probability of detecting the same processes. Note that the HERA energy (~ 300 GeV) is not enough to produce the process $c\gamma \to t\pi^0$(we plot it from 500 GeV) since the sum of the masses of the top quark and the top-pion boson is larger than 350 GeV , so the THERA, with higher CM energy, can open some processes that do not appear in the HERA collider, which is also the reason why we carry out our calculation at the THERA, but not at the HERA collider, i e, why we take the CM energy as 1 TeV.

Now we further consider the signature of $b\pi_t^\pm$ production at the γp collision since the rate of the $t\pi_t^0$ production is too low. For the process $\gamma p \to b\pi_\pm^+$, π_t^+ decays to $t\bar{b}$ and $c\bar{b}$ with the branching ratio about 70% and 30%, respectively, with the top quark to Wb and W to charge lepton and the missing energy, i.e, the $3b + l + \not{E}$ signal with $\not{E}$, the missing energy, so the mainly SM backgrounds are $j\gamma \to jWZ$ or jWh, with $W \to l \not{E}$ and $Z/h \to b\bar{b}$ and the jet j mis-detected as b quark. While the background cross sections are very small, about 1 fb, Therefore if the cuts such as, to the p_T^l etc., and the b-tagging skill are employed assuming 60% efficiency and 1% mis-tagging, the backgrounds will be depressed violently.

If we assume only one fortieth of signal is retained (considering the top decaying branching ration about 1/6 to the charged lepton, the signal may still be detected by the γp collider.

IV. SUMMARY AND CONCLUSION

In the framework of the TC2 models, we calculated the productions of a single top or bottom quark associated with a scalar in γ-p collision, which proceed via the subprocesses $c\gamma \to t\pi_t^0$, $c\gamma \to th_t^0$ and $c\gamma \to b\pi_t^+$ mediated by the anomalous top coupling $tc\pi_t^0$, tch_t^0 and $bc\pi_t^+$. These productions, with extremely small backgrounds in the Standard Model, were found to be significantly enhanced in the large part of the TC2 parameter space, especially the production via $c\gamma \to b\pi^+$ can have a cross section of 100 fb, which may be accessible and allow for a test of the TC2 models.

[1] For some reviews on top quark, see, e.g., W. Bernreuther, J. Phys. G**35**, 083001,(2008) D. Chakraborty, J. Konigsberg, D. Rainwater, Ann. Rev. Nucl. Part. Sci. **53**, 301 (2003); E. H. Simmons, hep-ph/0211335; hep-ph/0011244; C.-P. Yuan, hep-ph/0203088; S. Willenbrock, hep-ph/0211067; M. Beneke *et al.*, hep-ph/0003033; J. M. Yang, Annals Phys. **316**, 529 (2005); Int. J. Mod. Phys. A23, 3343 (2008); T. Han, arXiv:0804.3178;

[2] For model-independent studies, see , e.g., C. T. Hill, S. J. Parke, Phys. Rev. D **49**, 4454 (1994); K. Whisnant *et al.*, Phys. Rev. D **56**, 467 (1997); J. M. Yang, B.-L. Young, Phys. Rev. D **56**, 5907 (1997); K. Hikasa *et al.*, Phys. Rev. D **58**, 114003 (1998); J. A. Aguilar-Saavedra, arXiv:0811.3842; A. Datta, M. Duraisamy, Phys. Rev. D **81**, (2010) 074008;

[3] G. Eilam, J. L. Hewett, A. Soni, Phys. Rev. D **44**, 1473 (1991); B. Mele, S. Petrarca, A. Soddu, Phys. Lett. B **435**, 401 (1998); A. Cordero-Cid *et al.*, Phys. Rev. D **73**, 094005 (2006); G. Eilam, M. Frank, I. Turan, Phys. Rev. D **73**, 053011 (2006).

[4] C. S. Li, R. J. Oakes, J. M. Yang, Phys. Rev. D **49**, 293 (1994); G. Couture, C. Hamzaoui, H. Konig, Phys. Rev. D **52**, 1713 (1995); J. L. Lopez, D. V. Nanopoulos, R. Rangarajan, Phys.

Rev. D **56**, 3100 (1997); G. M. de Divitiis, R. Petronzio, L. Silvestrini, Nucl. Phys. B **504**, 45 (1997); C. S. Li, L. L. Yang, L. G. Jin, Phys. Lett. B **599**, 92 (2004); M. Frank, I. Turan, Phys. Rev. D **74**, 073014 (2006); J. M. Yang, C. S. Li, Phys. Rev. D **49**, 3412 (1994); J. Guasch, J. Sola, Nucl. Phys. B **562**, 3 (1999); J. Guasch, *et al.*, hep-ph/0601218; J. Cao, *et al.*, Nucl. Phys. B **651**, 87 (2003); Phys. Rev. D **74**, 031701 (2006); Phys. Rev. D **75**, 075021 (2007); Phys. Rev. D **79**, 054003 (2009); J. M. Yang, B.-L. Young, X. Zhang, Phys. Rev. D **58**, 055001 (1998); G. Eilam, *et al.*, Phys. Lett. B **510**, 227 (2001);

[5] H. S. Hou, Phys. Rev. D **75**, 094010 (2007); X.-F. Han, L. Wang, J. M. Yang, arXiv:0903.5491 [hep-ph]; X. Wang, *et al.*, Nucl. Phys. B **810**, 226 (2009).

[6] C. T. Hill, Phys. Lett. B **345**, 483 (1995); K. Lane and E. Eichten, Phys. Lett. B **352**, 383 (1995); K. Lane, Phys. Lett. B **433**, 96 (1998); G. Cvetic,Rev. Mod. Phys.bf 71, 513 (1999); C. T. Hill and E. H. Simmons, Phys. Rept. **381**, 235 (2003), [Erratum-ibid. **390**, 553 (2004)].

[7] See, e.g., H. J. He and C. P. Yuan, Phys. Rev. Lett. **83**, 28 (1999); C. Balazs, H.-J. He, C.P. Yuan, Phys. Rev. D **60**, (1999) 114001;H.-J. He, S. Kanemura, C.P. Yuan, Phys. Rev. Lett. **89**, (2002) 101803; Phys. Rev. D **68**, (2003) 075010; G. Burdman, Phys. Rev. Lett. **83**, 2888 (1999); T. Rador, Phys. Rev. D **59**, 095012 (1999); C. Yue, *et al.*, Phys. Lett. B **496**, 93 (2000); Commun. Theor. Phys. **37**, 447 (2002); Commun. Theor. Phys. **38**, 461 (2002); J. Cao, *et al.*, Phys. Rev. D **70**, 114035 (2004); Phys. Rev. D **67**, 071701 (2003); Euro. Phys. J. C **41**, 381 (2005); Phys. Rev. D **76**, 014004 (2007); F. Larios and F. Penunuri, J. Phys. G**30**, 895(2004); H. J. Zhang, Phys. Rev. D **77**, 057501 (2008); G. L. Liu, H. J. Zhang, Chin. Phys. C 32, 597 (2008); G. L. Liu, Chin. Phys. Lett.bf 26, 101401,2009; arXiv:1002.0659. .

[8] A. N. Akay, H. Karadeniz, S. Sultansoy, arXiv:0911.3314; S. Sultansoy, Euro. Phys. J. C **33**, (2004) 1064-1066; Conf. Proc. C 0505161, (2005) 4329; P. L. Csonka and J. Rees, Nucl. Instum. Meth. 96, 149 (1971).

[9] http://www.ifh.de/thera/tbook/index.html.

[10] H. Abramovitz, *et al.*, in TESLA TDR, DESY-2001-011, ECFA-2001-209 (2001); A. K. Ciftci, S. Sultansoy and O. Yavas, Nucl. Instr. Meth. A 472,72 (2001).

[11] O. Cakir, S. A. Cetin, A. DeRoeck, G. Guignard, D. Schulte, I. Wilson, and S. Sultansoy, Informal Meeting on CLIC-LHC Interface, 23 August 2002, CERN

[12] Y. Islamzade, H. Karadeniz, and S. Sultansoy, hep-ex/0207013; hep-ex/0204034.

[13] S. F. Sultanov, ICTP Preprint IC/89/409 (1989); S. I. Alekhin *et al.*, Int. J. Mod. Phys. A6, 21

(1991); A. K. Ciftci *et al.*, Nucl. Instrum. Meth. A365, 317 (1995); A. K. Ciftci, S. Sultansoy, O. Yavaş, Nucl. Instrum. Meth. A472, 72 (2001); H. Aksakal *et al.*, Nucl. Instrum. Meth. A576, 287 (2007).

[14] B. Balaji, Phys. Lett. B **393**, 89 (1997).

[15] Y. Nambu, "New Theories In Physics", Proc. XI Warsaw Symposium on Elementary Particle Physics, (ed. Z. Adjuk *et al.*, publ. World Scientific, Singapore, 1989); V.A. Miransky, M.Tanabashi and M. Yamawaki, Phys. Lett. B **221**, 177 (1989); R.R. Mendel and V.A. Miransky, Phys. Lett. B **268**, 384 (1991); W.A. Bardeen, C.T. Hill and M.Lindner, Phys. Rev. D **41**, 1647 (1990).

[16] B. A. Dobrescu, C. T. Hill, Phys. Rev. Lett. **81**, 2634 (1998); R. S. Chivukula, B. A. Dobrescu, H. Georgi, C. T. Hill, Phys. Rev. D **59**, 075003 (1999).

[17] G. Burdman, D. Kominis, Phys. Lett. B **403**, 101 (1997).

[18] Z. Z. Aydin, N. Karagoz, A. U. Yilmazer, hep-ph/0303036.

[19] A. T. Alan and A. Senol, Europhys. Lett. **59,** 669 (2002); A. A. Ashimova, S.R. Slabospitsky, Phys. Lett. B **668**, 282 (2008); F.D. Aaron *et al.*, (H1 Collaboration), Phys. Lett. B **678**, 450 (2009).

[20] I. F. Ginzburg, *et al.*, Nucl. Instrum**219**, 5 (1984); V. I. Telnov, Nucl. Instrum. Meth.**294**, 72 (1990).

[21] J. Pumplin, A. Belyaev, J. Huston, D. Stump and W. K. Tung, JHEP **0602**, 032 (2006).

[22] C. Amsler, *et al.* (Particle Data Group), Phys. Lett. B **667**, 1 (2008).

[23] C. Yue, et. al, Phys. Lett. B **575**, 25 (2003).